Lee & Wittich

The Influence of Varying Reactance upon the short Circuit Phenomena in Alternators

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THE INFLUENCE OF VARYING REACTANCE UPON THE SHORT CIRCUIT PHENOMENA IN ALTERNATORS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Everett Samuel Lee and Fred Peter Wittich

ENTITLED The Influence of Varying Reactance upon the Short Circuit Phenomena in Alternators.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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THE INFLUENCE OF VARYING REACTANCE UPON THE SHORT CIRCUIT PHENOMENA IN ALTERNATORS.

I. INTRODUCTION.

Of the several phenomena which occur in the armature of an alternating current generator when it is subjected to short-circuit, the one of most interest and importance is the magnitude and duration of the first rush of current. At the instant the short-circuit occurs the current is limited only by the self inductance of the armature, which varies in magnitude as the position of the armature changes with respect to the field poles. It is evident, therefore, that the first rush of current will vary in magnitude depending upon the value of the self-inductive reactance of the armature for that angle of the e. m. f. wave when the short-circuit occurs.

Several theoretical formulae have been deduced from which the value of the short-circuit current can be calculated, and it is one object of this thesis to determine the applicability of such a formula, as derived in the thesis of Mr. P. G. Gray (No. G.79,1912), to actual results as determined by experiment.

Of equal interest to the investigator is the amount of torque exerted upon the shaft at the instant of short-circuit. As in the case of the maximum rush of short-circuit current a

formula has been derived from which the power at short-circuit can be calculated, and as it is evident that the power is dependent upon the value of the reactance of the armature, it is essential to know whether reliable results can be obtained by using an average value of reactance or whether the actual value of reactance for that point on the e.m.f. wave when the short-circuit occurs must be used.

To investigate the applicability of these formula to short-circuit phenomena is the purpose of this thesis.

II. GENERAL THEORY.

The relation of the electromotive forces and magnetomotive forces in the armature of an alternating current generator can be studied to the best advantage by use of the vector diagram.

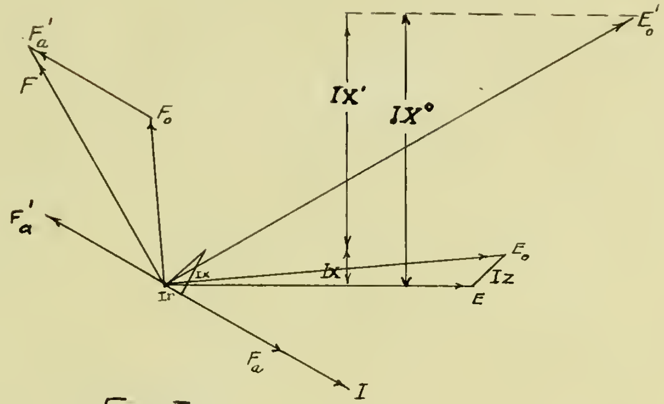


Fig. I.

Referring to Fig. I., the current I lagging behind the terminal e.m.f. E, produces in the armature an impedance drop Iz, which added to E, gives E_o the voltage which must be induced in the armature. To induce the voltage E_o, a flux F_o is required which is produced by the m.m.f. of the field ampere turns. The current I, however, produces a m.m.f., F_a, in phase with itself, which must be overcome by an equal and opposite force F_a', also produced by the m.m.f. of the field. The resultant of the two forces F_o and F_a' is F which represents the total m.m.f. that must be furnished by the field ampere turns. If the armature is now open-circuited, the field remaining unchanged, a voltage E_o' will be induced, the magnitude of which depends upon the shape of the magnetization curve of the iron. The distance IX represents the self inductive reactance of the

armature; IX' represents the reactance due to the armature reactions in the armature; IX_o represents the combined effect of the two reactances and is known as the synchronous reactance.

At short-circuit, the permanent short-circuit current I lags practically 90° behind the electromotive force. (Fig. II.) The terminal voltage being zero, the e.m.f. E_o is equal to the reactance drop in the armature, and is produced by the flux due to the m.m.f. F_o, of the field. The armature current also produces a m.m.f. F_a, which now opposes the field directly, and must be overcome by an equal and opposite m.m.f., F_a'. The resultant of F_a' and F_o is F, which is a measure of the total m.m.f. which the field ampere turns must furnish. If the short-circuit is now removed, the field remaining unchanged, the terminal voltage will rise to a value E_o', and as in Fig. I.; IX, IX', and IX_o, represent in magnitude the self induced reactance, the armature reaction reactance, and the synchronous reactance of the armature, respectively.

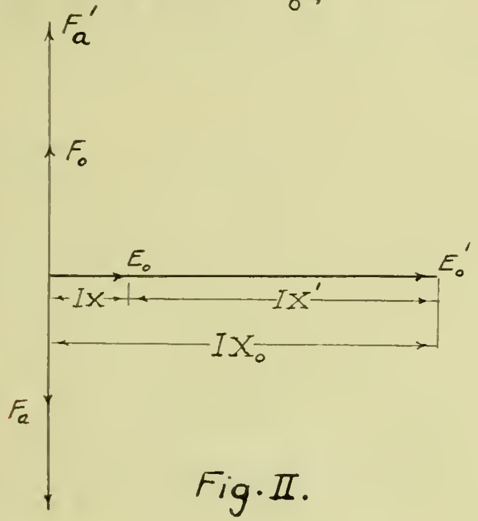


Fig. II.

The maximum rush of current when the armature of an alternating current generator is short-circuited is very great, reaching as high a value as ten times normal full-load current. The maximum values of current, however, decrease in each successive cycle according to a logarithmic law until the per-

manent short-circuit current is reached, which is about twice as great as normal full-load current, and is determined in value by the magnitude of the synchronous reactance of the armature as illustrated in Fig. II. above.

The magnitude of the first rush of current is determined by the true self-inductive reactance of the armature. Considering for a moment the formula for the short-circuit current, as given by Mr. Gray in his thesis, which takes the form,

$$i = \frac{E}{X}\left[\epsilon^{-\frac{r_o}{X_o}(\theta-\theta_1)} \sin\left(\theta-\beta+\frac{2\pi(m-1)}{n}\right) - \epsilon^{-\frac{r}{x}(\theta-\theta_1)} \sin\left(\theta_1-\beta+\frac{2\pi(m-1)}{n}\right)\right]$$

It is clear that the value of the current depends upon the term X, which is the reactance of the armature of the alternator. It is usual to assume the value of X to be constant, irrespective of what angle on the e.m.f. wave the short-circuit occurs. But this assumption is not correct since the reactance of the armature varies with the relative position of the armature and the field poles.

Just what causes this variation in reactance can be seen from Figs. III. and IV., which represent sections of the armature and field poles. When a conductor is facing a pole, the reluctance of the magnetic path for the flux produced by the current in the conductor is low, the path being practically all iron, and the flux reaches a maximum value, causing maximum self-inductance. When the conductor has passed to a position

between the poles, however, the magnetic circuit being practically

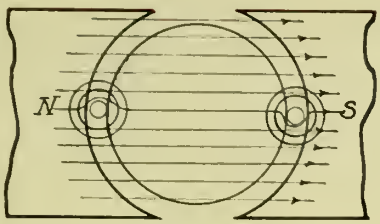


Fig. III.

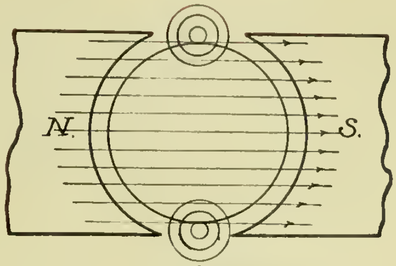


Fig. IV.

of air, the reluctance is great and the flux is small causing a low inductance. Hence the inductance is a pulsating one, reaching a maximum when the conductor is opposite to a pole, and decreasing to a minimum when the conductor is between two poles.

Due to the fact, that the armature reactance pulsates, it would seem more logical to obtain the values of reactance for different points on the e.m.f. wave, and use these actual values in calculating the magnitude of the current produced when the armature is short-circuited at any known point on the e.m.f. wave; rather than using an average value of reactance or the synchronous reactance, as in the methods commonly employed.

To obtain the relative accuracy between the values of short-circuit current, obtained by using either the average value of reactance or the actual value of reactance, and experimental data, the calculations and tests recorded in this thesis were made. Having determined the constants and the reactance waves of two machines, the maximum values of short-circuit current for successive closing points on the e.m.f. wave were calculated

using (a) an average value of reactance, constant for all angles of closing; and (b) the true value of armature reactance for the respective angles of closing. Oscillograms were then obtained giving the experimental values of current for different angles of short-circuit on the e.m.f. wave. Comparing the calculated data with experimental results, it would seem that the values of current obtained by using the actual values of reactance are more accurate than those values calculated using an average reactance.

III. CALCULATIONS AND TESTS.

INVESTIGATION OF SHORT-CIRCUIT CURRENT. Two machines were employed in the tests, both of which are in the Electrical Engineering Laboratory at the University of Illinois. Machine No. 1 was a 15 K. W., 240 Volt, Y connected rotating armature, three phase alternator, direct connected to a 220 volt 25 horsepower D. C. motor, #F00299, manufatured by the General Electric Company. The constants were found to be:-

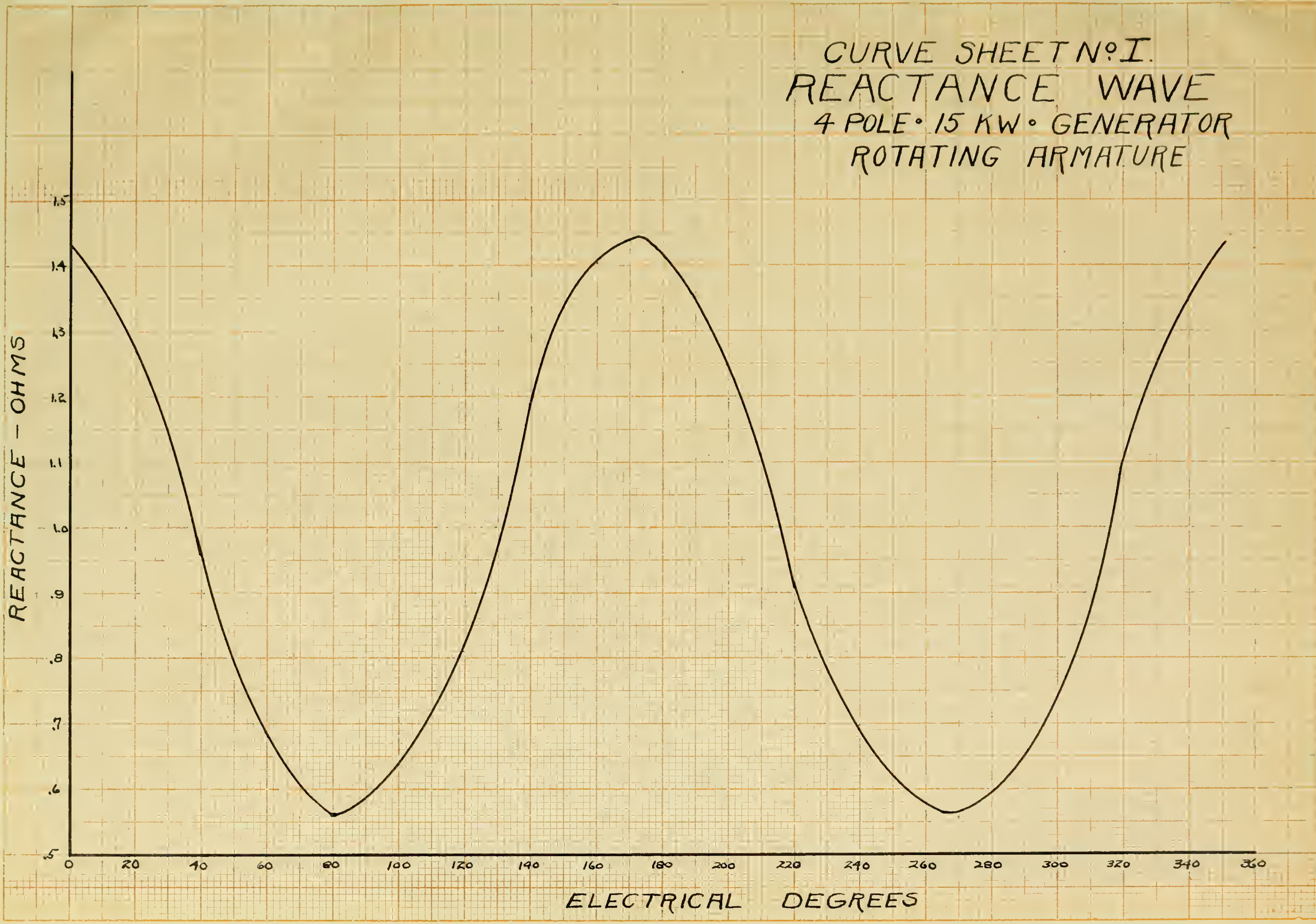
	Armature		Field.
r	.0916 ohms	r_o	31.4 ohms
x	1. 0 ohms (mean value)	x_o	8600 ohms

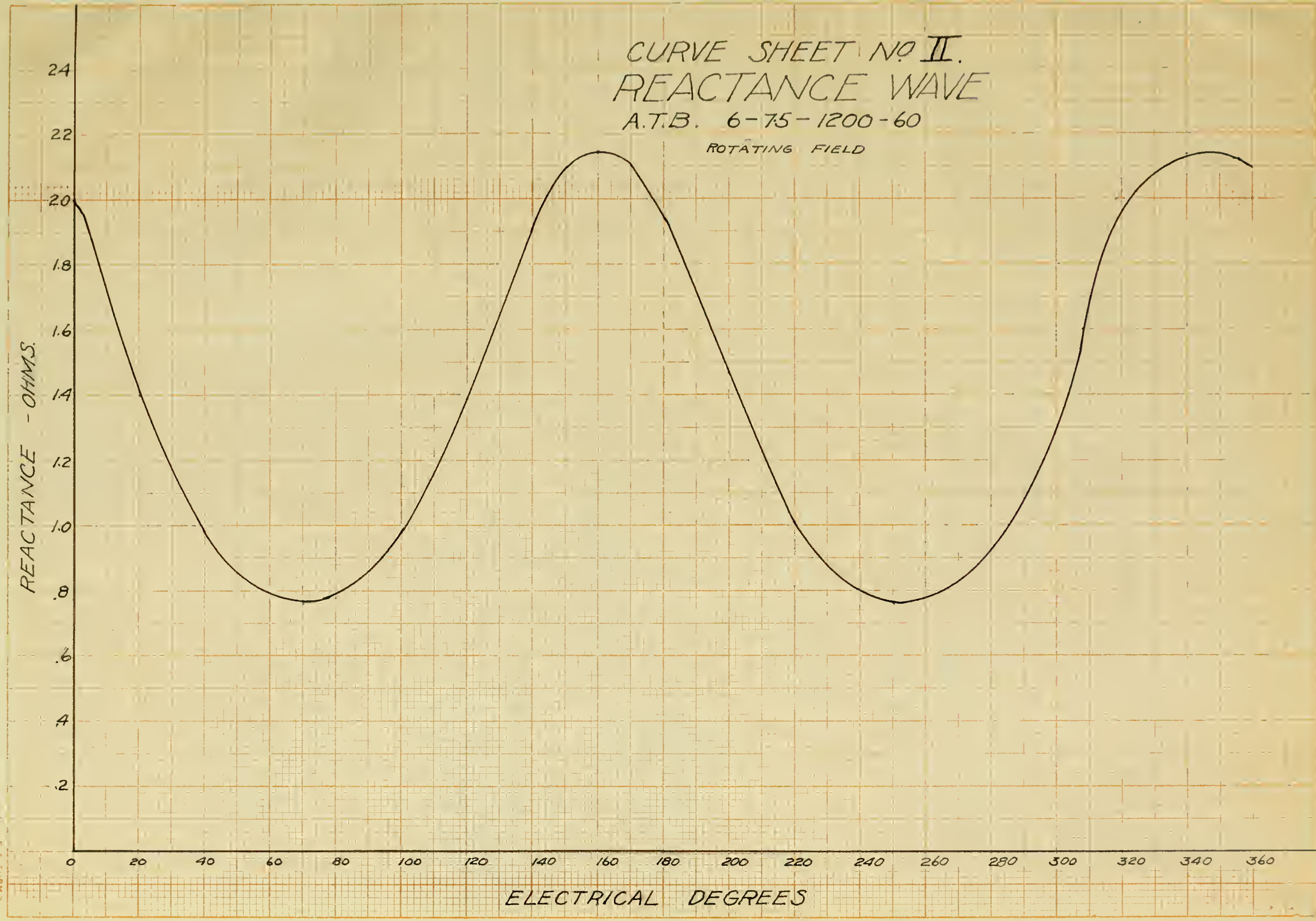
Machine No II. was a 7.5 K. W., 220 volts, rotating field, six pole, 2 phase, alternator #45584, manufactured by the General Electric Company. The constants were found to be:-

	Armature		Field
r	.540 ohms	r_o	21.66 ohms
x	.86 ohms (mean value)	x_o	754 ohms

The reactance wave of machine No 1 (curve sheet No I page 9) was determined by short-circuiting the fields and measuring the voltage drop in the amature, full load current flowing, for every 10° position of the armature with respect to the field poles from 0° to 360°.

The reactance wave of machine No II. (curve sheet No II page 10) was plotted from the data found in Mr. Gray's thesis.


CURVE SHEET No. I.
REACTANCE WAVE
4 POLE • 15 KW • GENERATOR
ROTATING ARMATURE
REACTANCE - OHMS
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
ELECTRICAL DEGREES


CURVE SHEET No. II.
REACTANCE WAVE
A.T.B. 6-7.5-1200-60
ROTATING FIELD
REACTANCE - OHMS.
ELECTRICAL DEGREES
24
22
20
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

Having the constants and reactance waves of the machines, the maximum value of short-circuit current for every 30° on the e.m.f. wave was calculated, using (a) a mean value of reactance; and (b) the true value of reactance for each respective angle of short-circuit on the e.m.f. wave, for which the sample calculations are shown in Table I., pages 11-12 and on curve sheet No 3 page 13 .

Constants of Rotating Armature Machine

$\frac{r_o}{x_o} = .00365$ $E_m = 240\sqrt{2} = 339$ volts Constant $x = 1$

$\frac{r}{x} = .092$ $\theta = 90^\circ$ $\beta = 85^\circ$

θ	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	360°
Radions $(\theta-\theta_1)$	-1.023	-.523	0	.523	1.023	1.57	2.1	2.62	3.142	3.66	4.2	4.72
$\frac{r_o}{x_o}(\theta-\theta_1)$	-.00374	-.0019	0	.0019	.00374	.00573	.00766	.00956	.0115	.01338	.01535	.0173
$\varepsilon^{-\frac{r_o}{x_o}(\theta-\theta_1)}$	1.003	1.001	1	.998	.996	.994	.9923	.9905	.9885	.9865	.9846	.9828
$\theta_1-\beta$	-55°	-25°	5°	35°	65°	95°	125°	155°	185°	215°	245°	275°
$\sin(\theta-\beta)$	-.8192	-.4226	.0872	.5736	.9063	.9963	.8192	.4226	-.0872	-.5736	-.908	.9962
$\varepsilon^{-\frac{r_o}{x_o}(\theta-\theta_1)}\sin(\theta_1-\beta)$	-.82	-.426	.0872	.5736	.904	.991	.813	.380	-.0862	-.566	-.895	-.980
$\frac{r}{x}(\theta-\theta_1)$	-.0094	-.00482	0	.00482	.0094	.01445	.0193	.0232	.0289	.0337	.0386	.0434
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	1.01	1.005	1	.995	.9905	.986	.981	.9768	.9715	.9666	.962	.957
$(\theta_1-\beta)$	5°	–	–	–	–	–	–	–	–	–	–	–
$\sin(\theta_1-\beta)$	.08716	–	–	–	–	–	–	–	–	–	–	–
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}\sin(\theta_1-\beta)$	.088	.0872	.0872	.0867	.0863	.086	.0855	.0852	.0847	.0843	.0838	.0835
E/X	339	–	–	–	–	–	–	–	–	–	–	–
$(a-b)$	-.908	-.513	0	.4868	.818	.905	.728	.295	0	-.55	-.909	-1.06
$\frac{E}{X}(a-b)=i$	-308	-174	0	165	280	308	247	100	0	-187	-336	-394

Constants of Rotating Armature Machine.

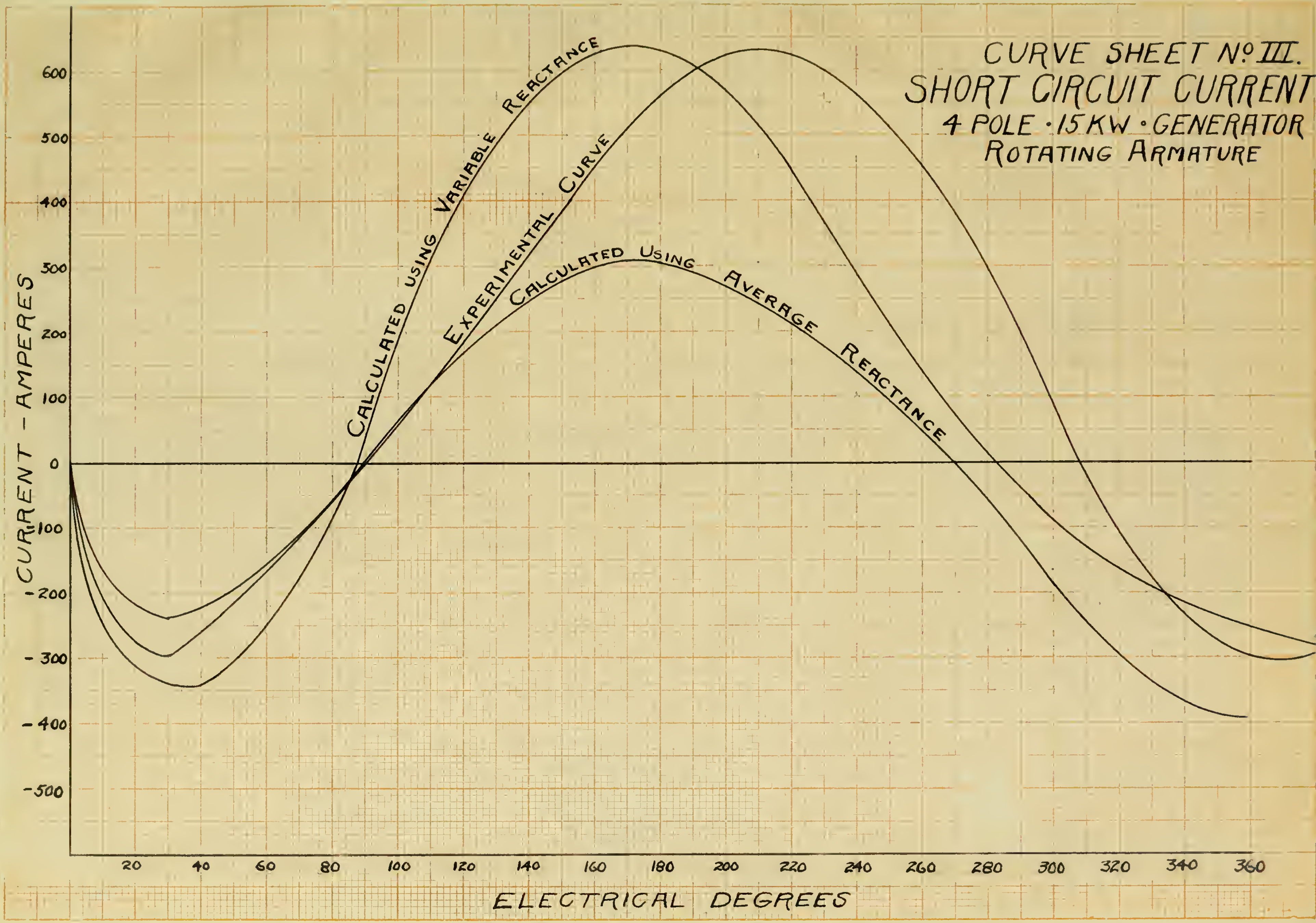
Variable X

$\frac{r_0}{X_0} = .00365$ $\qquad E_m = 240\sqrt{2} = 339$ volts

$\theta_1 = 90°$

θ	30°	60°	90°	160°	185°	210°	225°	240°	270°	300°	355°
$(\theta - \theta_1)$ Radians	-1.022	-.522	0	1.22	1.66	2.10	2.35	2.62	3.142	3.60	4.62
$\frac{r_0}{X_0}(\theta - \theta_1)$	-.00372	-.00191	0	.00445	.00605	.00765	.00856	.00954	.01148	.01315	.01685
$\varepsilon^{-\frac{r_0}{X_0}(\theta-\theta_1)}$	1.003	1.001	1	.9955	.994	.9922	.9915	.9905	.9885	.987	.983
x	.86	1.31	1.43	.555	.63	.82	1.03	1.26	1.45	1.085	.555
$\frac{r}{x}$	.107	.0702	.0643	.166	.146	.1122	.0893	.073	.0635	.0848	.166
$\left[\frac{r}{x} - \frac{r_0}{X_0}\right] = \frac{R}{X}$	.1034	.0665	.06065	.1624	.1424	.1086	.0857	.0694	.05955	.08115	.1624
$\frac{X}{R}$	9.66	15.05	16.5	6.15	7.02	9.21	11.66	14.41	16.7	12.3	6.15
$\beta = [\tan^{-1}\frac{X}{R}]$	84°5′	86°15′	86°25′	80°45′	81°55′	83°50′	85°5′	86°5′	86°35′	85°20′	80°55′
$\theta - \beta$	-54°5′	-26°15′	3°35′	79°15′	103°5′	126°10′	139°55′	153°55′	183°25′	214°40′	274°5′
$\sin(\theta - \beta)$											
$\beta_{AVG} = [\tan^{-1}\frac{X}{R}]$	83°30′										
$(\theta - \beta)$	-53°30′	-23°30′	6°30′	72°30′	101°30′	126°30′	141°30′	156°30′	186°30′	216°30′	271°30′
$\sin(\theta - \beta_{AVG})$	-.8	-.4	.1132	.9537	.9799	.8039	.6225	.3987	-.1132	-.5948	-.9997
$a = \varepsilon^{-\frac{r_0}{X_0}(\theta-\theta_1)} \sin(\theta - \beta_{AVG})$	-.8024	-.40	.1132	.948	.970	.797	.617	.395	-.1118	-.587	-.983
$(\theta_1 - \beta_{AV})$	6°30′										
$\sin(\theta_1 - \beta)$	.1132										
$\frac{r}{x}(\theta - \theta_1)$	-.1095	-.0366	0	.2025	.2422	.228	.210	.1914	.1995	.305	.767
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)}$	1.105	1.040	1	.86	.83	.84	.855	.865	.86	.785	.47
$\varepsilon^{-\frac{r}{x}(\theta-\theta_1)} \sin(\theta_1 - \beta) = b$	-.125	-.1178	.1132	.0974	.094	.095	.0967	.098	.0973	.0888	.0543
$(a - b)$	-.9274	-.5178	.2264	1.0454	1.064	.892	.7137	.493	.0145	-.498	-.938
$i = \frac{E_m}{x}(a - b)$	-366.5	-103.5	33.75	640	574	370	235.5	133	33.9	-156	-575

Using the calculated values of maximum current, two waves were plotted (curve sheet No. 4 page 14) showing the relation between the value of maximum current and the angle of short-circuit on the e.m.f. wave. On this curve sheet has also been plotted the experimental values of maximum current as were obtained with the oscillograph.


CURVE SHEET No. III.
SHORT CIRCUIT CURRENT
4 POLE · 15 KW · GENERATOR
ROTATING ARMATURE
CALCULATED USING VARIABLE REACTANCE
EXPERIMENTAL CURVE
CALCULATED USING AVERAGE REACTANCE
CURRENT - AMPERES
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
ELECTRICAL DEGREES

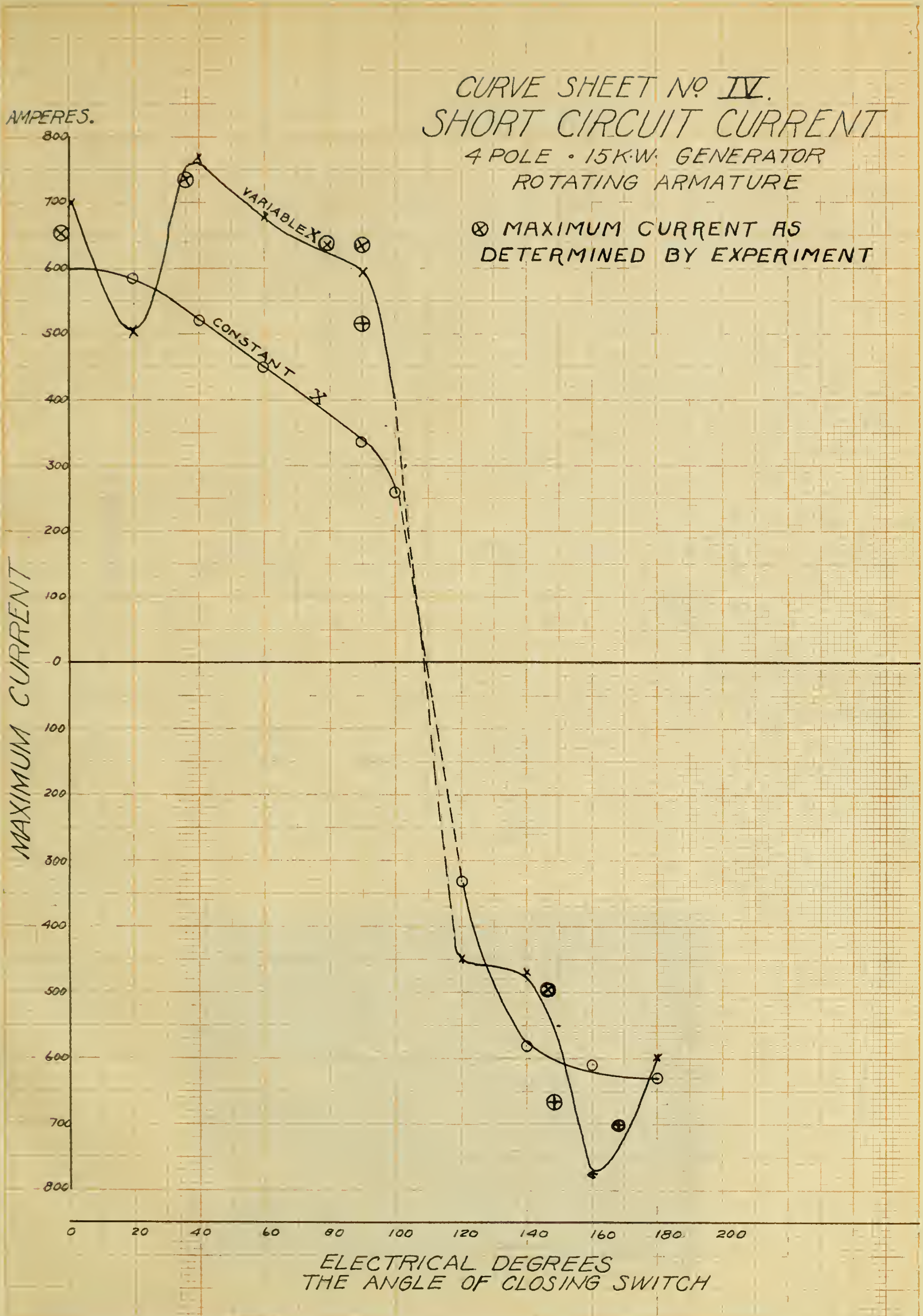

CURVE SHEET No IV.
SHORT CIRCUIT CURRENT
4 POLE • 15 K.W. GENERATOR
ROTATING ARMATURE
⊗ MAXIMUM CURRENT AS DETERMINED BY EXPERIMENT
AMPERES.
MAXIMUM CURRENT
VARIABLE
CONSTANT
800
700
600
500
400
300
200
100
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
140
160
180
200
ELECTRICAL DEGREES
THE ANGLE OF CLOSING SWITCH

Figure V. page 15 , shows the diagram of connections for the oscillograph, alternator and short-circuiting device which were employed in the tests.

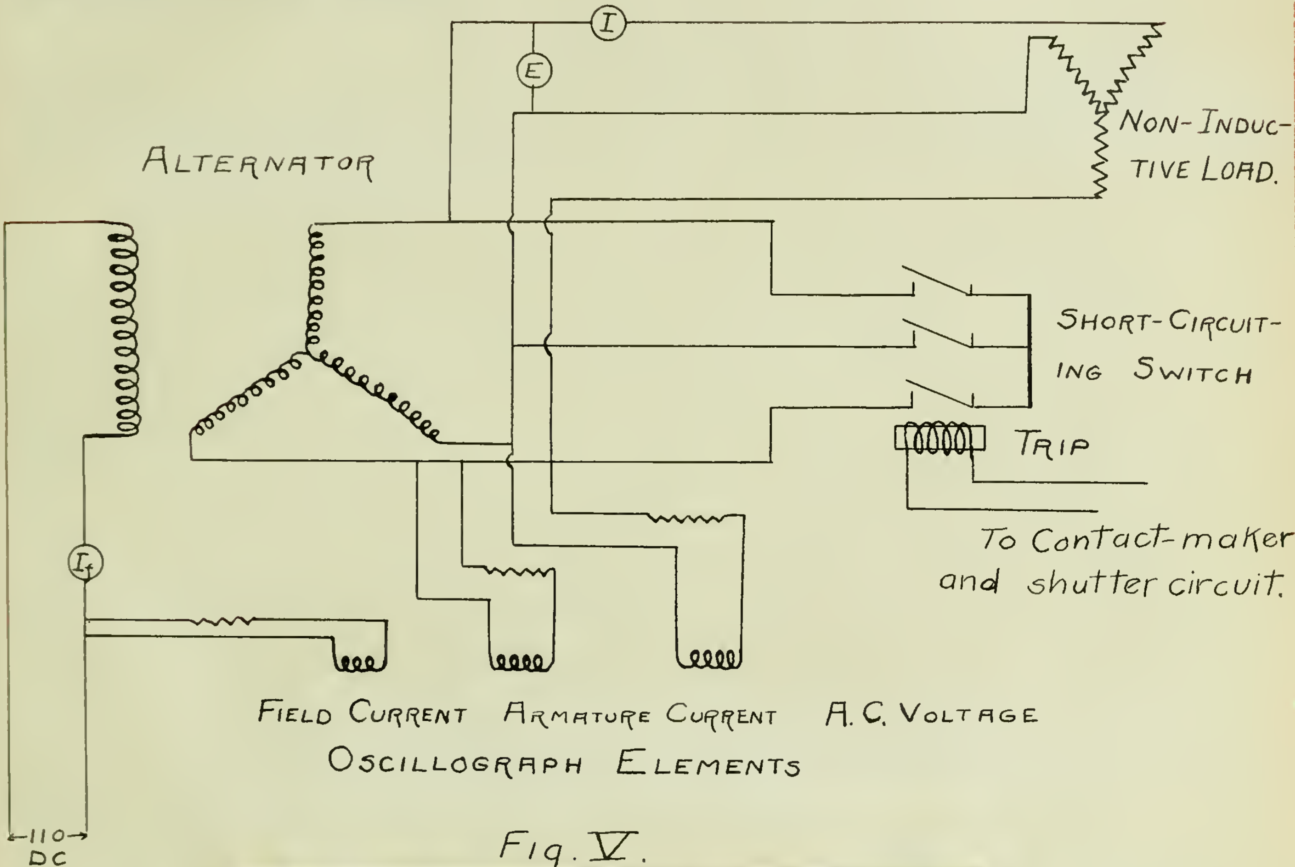
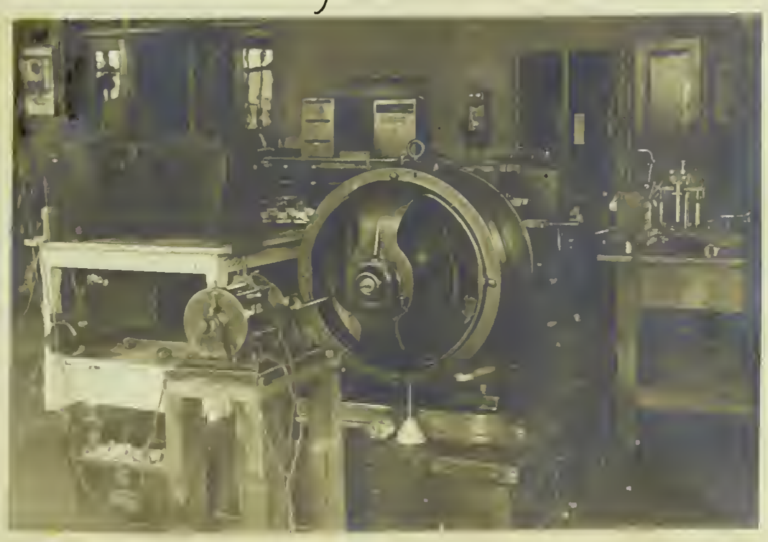


Fig. V.



A General Electric Oscillograph was used, with a combination short-circuiting attachment that closed the short-circuiting switch and opened the oscillograph shutter automatically. The alternator was run for each test at normal frequency and voltage with full non-inductive load, and subjected each time to a complete three phase short-circuit.

Much time was spent in an effort to obtain consistent results with an alternating current circuit closing machine, designed and made by Mr. G. D. Bagley, and described in his Master's Thesis of 1913. This machine when working properly, would close the short-circuiting switch at any pre-determined point on the e.m.f. wave. The machine would not give favorable resupts however, so oscillograms were taken at random with the hope that enough different closing points would be obtained from which the data necessary for comparison could be determined. Considerable difficulty was also experienced in finding a serviceable short-circuiting switch. After experimenting with several devices, a switch of the following form was used. A three pole knife switch was held open against the tension of a spring by means of a vertical bar which was balanced against a projection on the armature of an electromagnet. Energizing the magnet displaced the bar and allowed the switch to close. The magnets of the oscillograph shutter and of the switch

operated in the same circuit in such a manner that the switch closed just after the opening of the shutter.

III. (b) INVESTIGATION OF SHORT-CIRCUIT POWER. The investigations of the applicability of the theoretical short-circuit power equations to experimental results were made with some difficulty.

From the formula -

$$P = \frac{E^2 n}{2X}\left[\epsilon^{-\frac{2r_o}{X_o}(\theta-\theta_1)}\cos\beta - \epsilon^{-\left(\frac{r}{X}+\frac{r_o}{X_o}\right)(\theta-\theta_1)}\cos\left(\theta-\theta_1-\beta\right)\right]$$

as given by Mr. Gray, calculations were made of values of power for different points of short-circuit on the e.m.f. wave; using (a) constant reactance, and (b) variable reactance for the respective angles of short-circuit.

The experimental values of power were determined by retardation tests as explained by Mr. F. W. Herlan in "The Electrical Review and Western Electrician" for August 27, 1910, page 415. A retardation test is one in which the driving power is removed from a machine when it is running normally, and a record made of the speed for equal time increments as the revolving element comes to rest. From the data obtained, a curve is plotted between speed in R. P. M. and time in seconds from which the deceleration is determined. Mr. Herlan proves that the rate at which the energy is dissipated by the losses occuring in the machine is given by the expression:-

$$\text{Watts} = 1.662\ NJn.$$

Where N is the speed in R.P.S. when the angular deceleration $= \alpha$; and $\alpha = 2\ n$, when n is the deceleration in revolutions per second per second as determined from the speed-time curve described above. J is the moment of inertia of the armature, determined as follows: The alternator was driven as a synchronout motor and the electrical power imput measured. The power was now cut off and the decrease in speed determined for equal time increments. Plotting a curve between R.P.M. and seconds (curve sheet No. VI. page 19), n was determined, since

$$n = \frac{\text{R.P.M.}}{60 \times t \text{ seconds}}$$

Then substituting in the equation for power

$$J = \frac{\text{Watts}}{1.662\ Nn}$$

the moment of inertia J can be calculated.

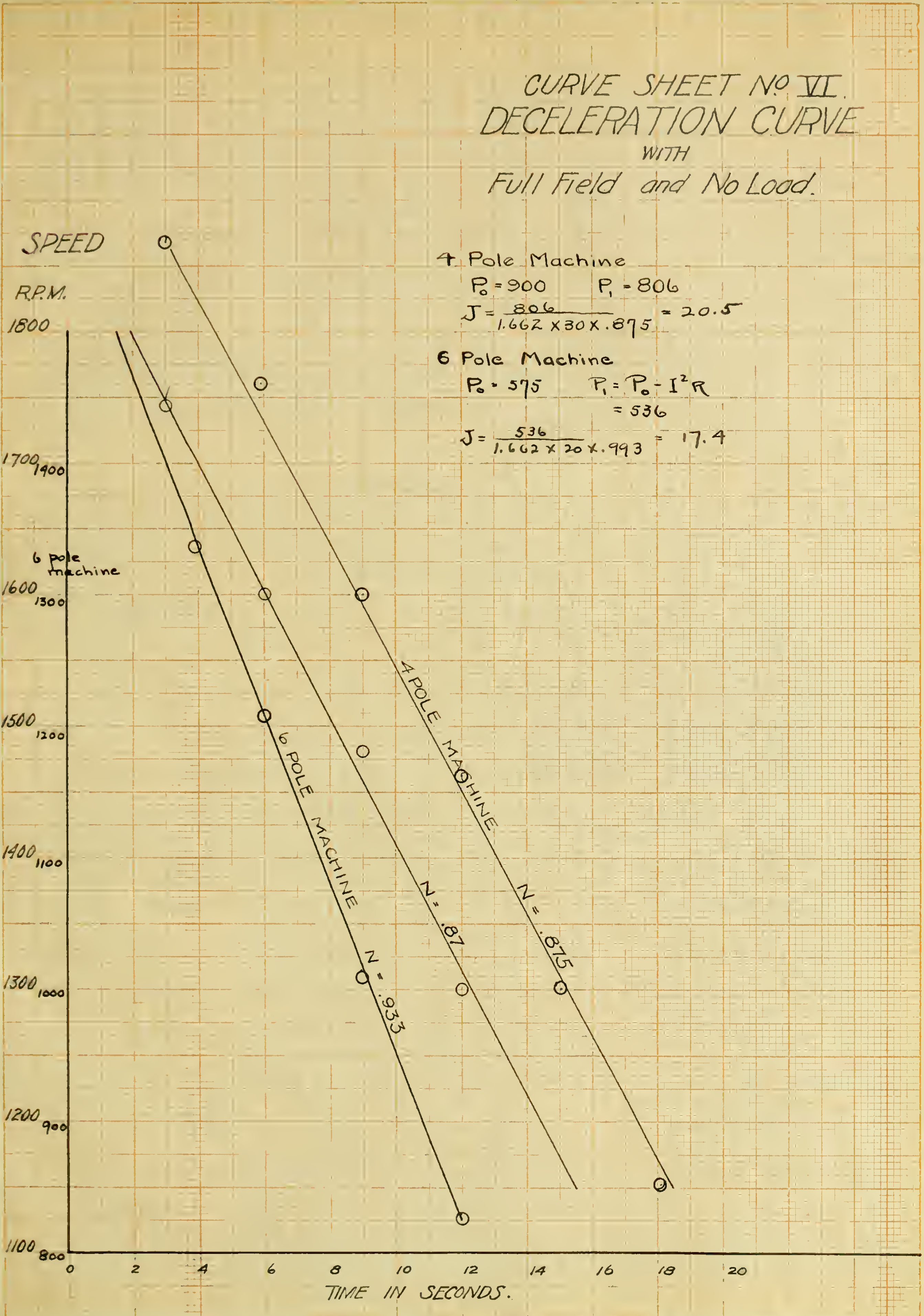

CURVE SHEET No VI.
DECELERATION CURVE
WITH
Full Field and No Load.
4 Pole Machine
$P_o = 900$ $P_1 = 806$
$J = \frac{806}{1.662 \times 30 \times .875} = 20.5$
6 Pole Machine
$P_o = 575$ $P_1 = P_o - I^2R$
$= 536$
$J = \frac{536}{1.662 \times 20 \times .993} = 17.4$
SPEED
R.P.M.
1800
1700 1400
6 pole machine
1600 1300
1500 1200
1400 1100
1300 1000
1200 900
1100 800
0
2
4
6
8
10
12
14
16
18
20
TIME IN SECONDS.
4 POLE MACHINE
N = .875
N = .87
6 POLE MACHINE
N = .933

Figure VI. page 20 is a diagram of connections to determine the short-circuit power.

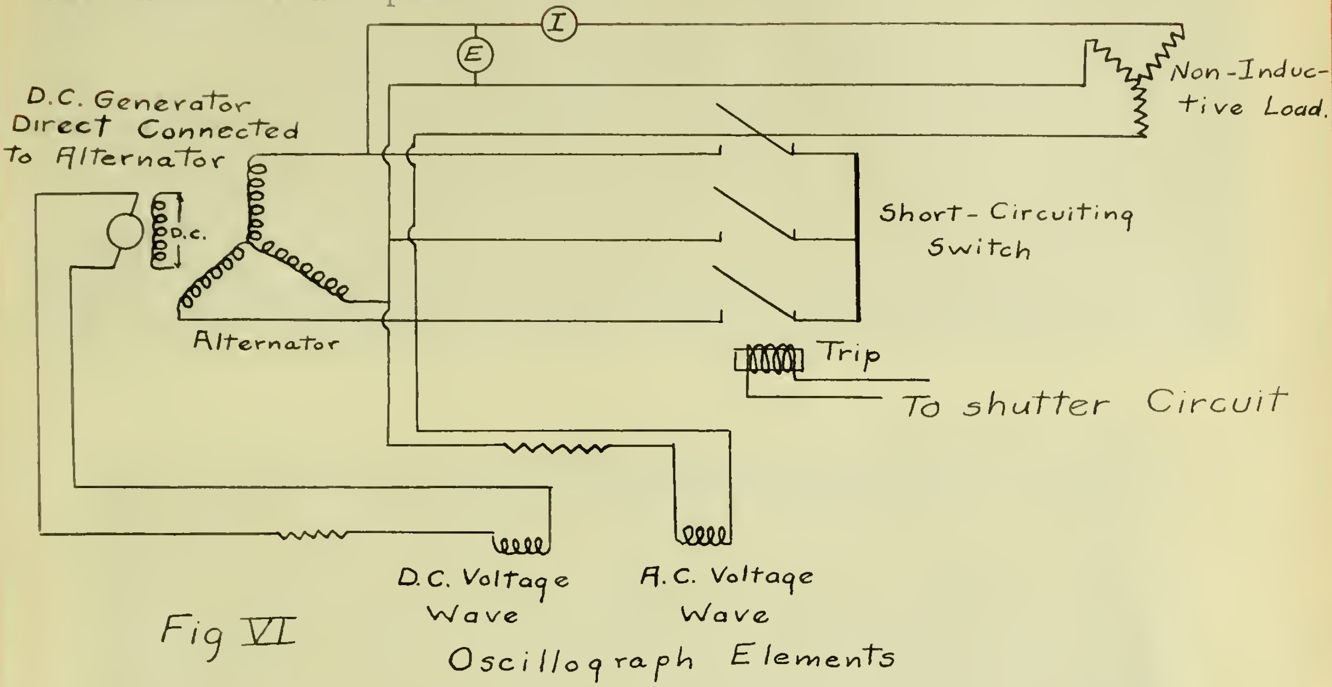
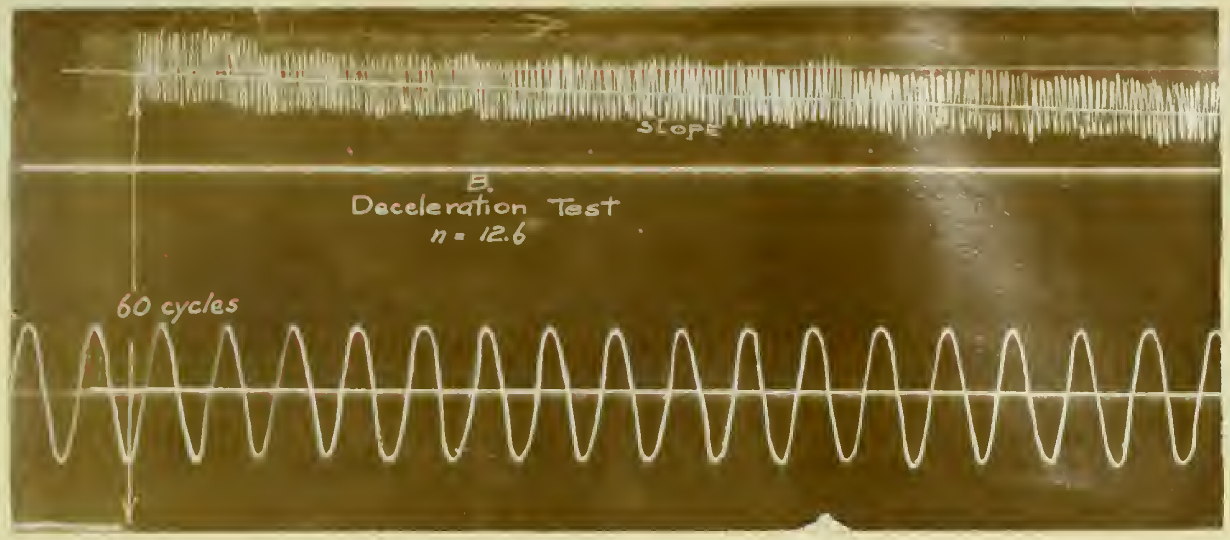
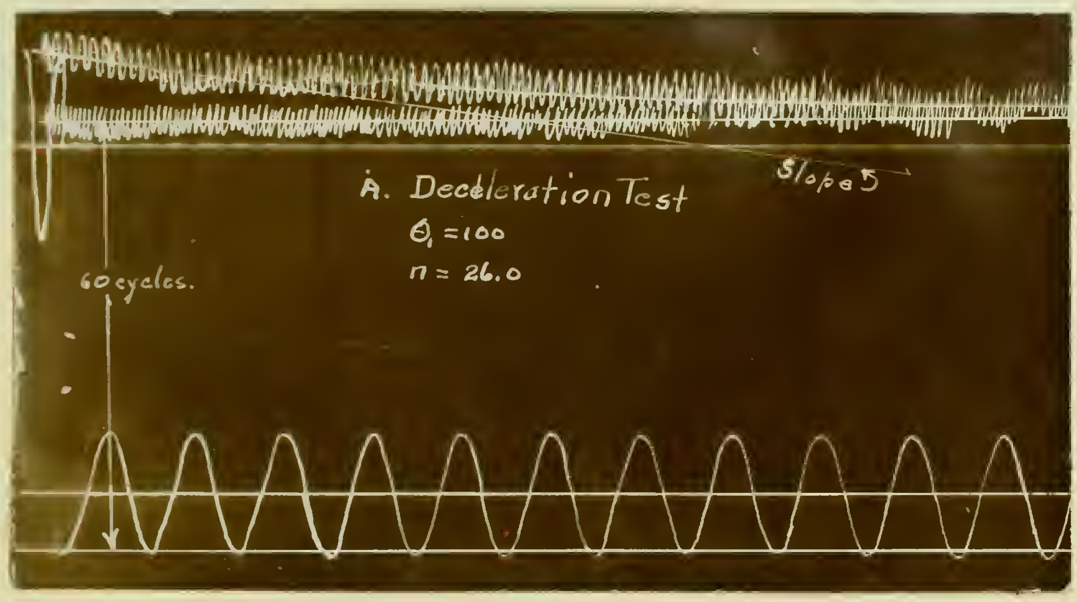


Fig VI

Two elements of the oscillograph were used,-- one to record the A. C. voltage wave, the other to record the voltage produced at the terminals of a small D. C. generator coupled to the shaft of the alternator under test. As the speed of the armature of the alternator decreased after short-circuit, the driving power being removed, the voltage of the D. C. generator decreased in proportion, Hence, the D. C. voltage wave on the oscillogram was a slanting one, and was an indication of the deceleration, which from a 60 cycle calibration wave, could be reduced to revolutions per second per second, which are the units of n required in the deceleration equation on page . Oscillograms No. I and No. II. show the results of two deceleration tests. Although the slope of the D. C. voltage wave is not perfectly definite, an average line has been drawn as shown, and from the slope of this line, the value of n was determined.

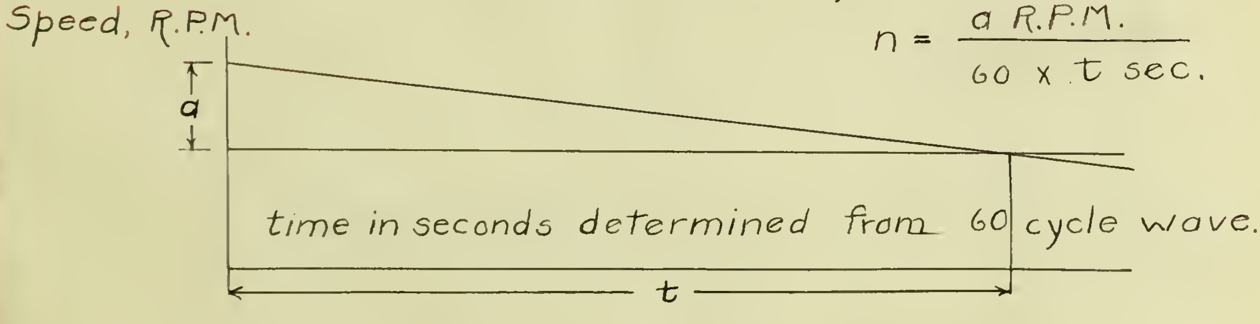


Oscillogram No. I.



Oscillogram No. 2.

Method of Calculating "n"



Having determined the value of n for each test, and knowing previously the value of J, the watts dissipated can be calculated and the value of the short-circuit torque derived from the equation:

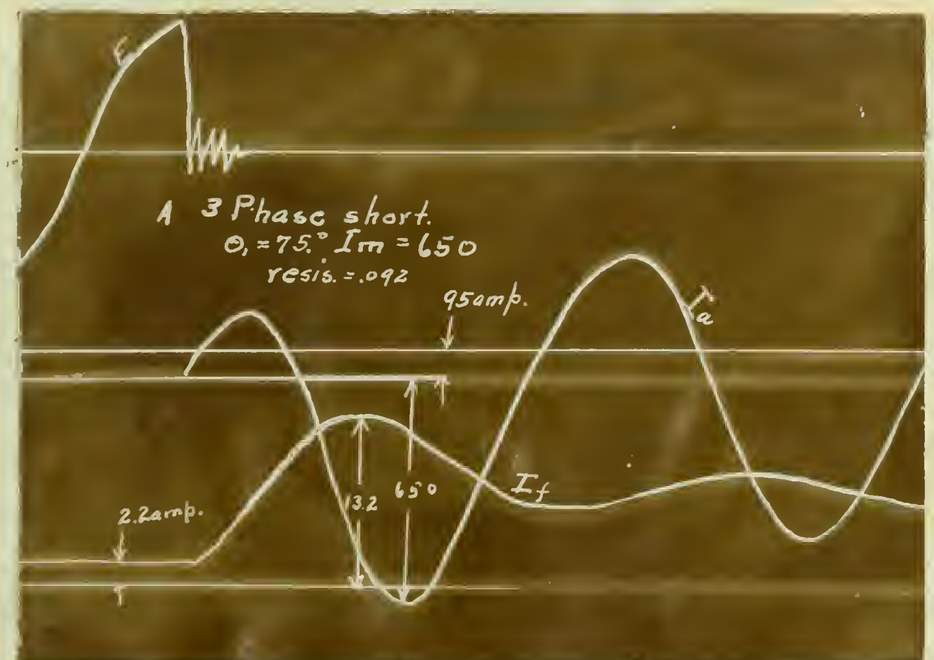
$$\text{Watts} = 1.662\ NJn.$$

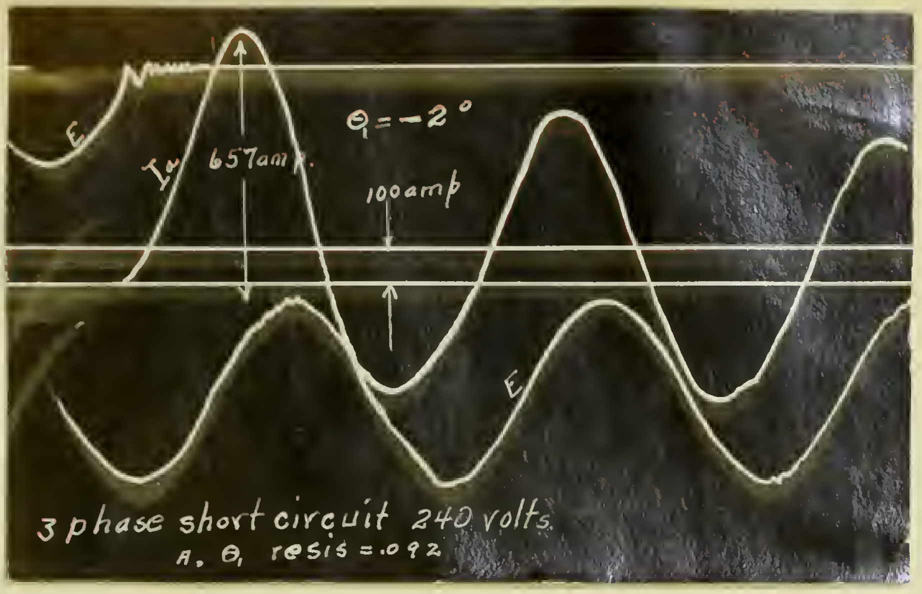
Each retardation test was performed by running the alternator at normal load, speed and voltage. In taking an oscillogram, the driving force was first removed from the alternator, then the oscillograph shutter was opened and the short-circuiting switch automatically closed, all three operations occuring in succession as rapidly as possible.

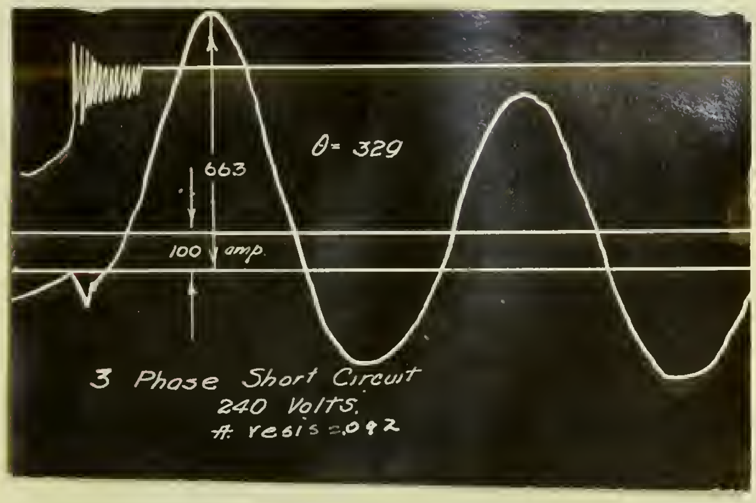
IV.

DISCUSSION OF RESULTS.

Short-Circuit Current Tests. The results obtained from calculations and tests made on the rotating armature machine are combined on curve sheet No IV., page 14. A study of these curves will show that the experimental values of short-circuit current correspond very closely to those values obtained by using variable values of reactance in the formula for short-circuit current. While the maximum values of current do not always come upon the same angle on the e.m.f. wave, this fact is not objectionable, since it is the maximum rush of current that is the important feature of the short-circuit phenomena. The following oscillograms show short-circuit tests on the rotating armature machine (machine No. 1.):




E
I_A
657 amp.
$\Theta_1 = -2°$
100 amp
E
3 phase short circuit 240 volts.
A. Θ_1 resis = .092


663
θ = 32.9
100 amp.
3 Phase Short Circuit
240 Volts.
A. resis = .092

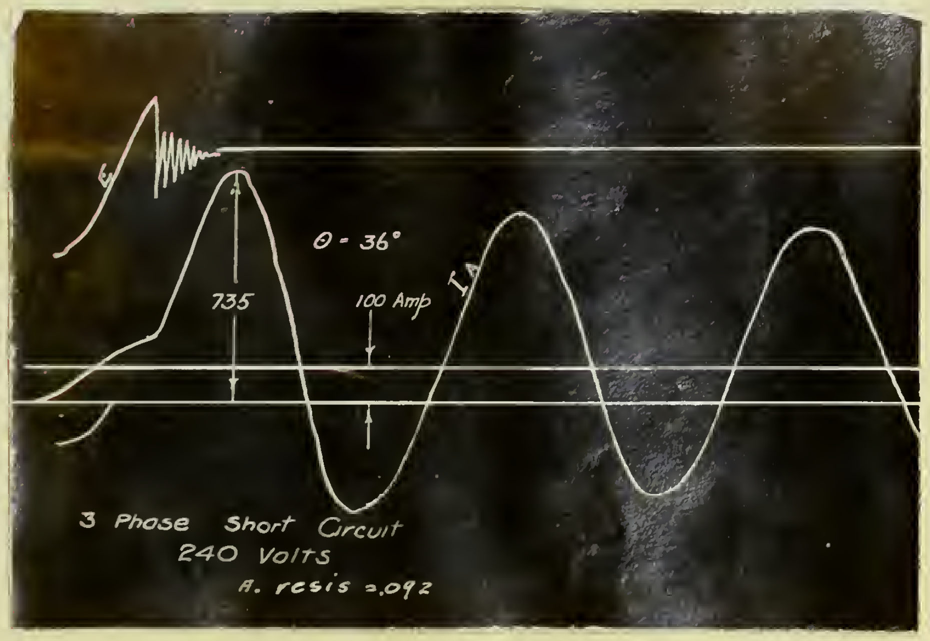
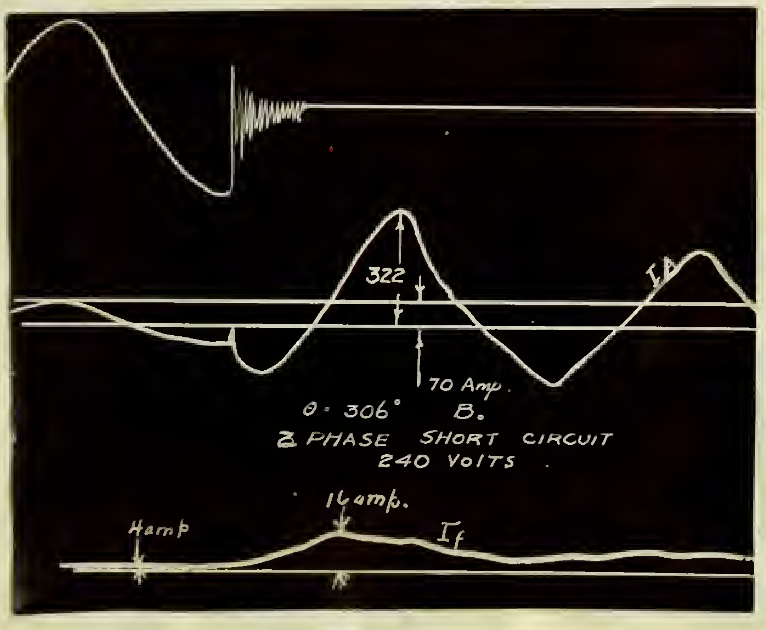

E
θ = 36°
735
100 Amp
I_A
3 Phase Short Circuit
240 Volts
A. resis = .092

Table II. gives the summarized data from the tests and calculations on the rotating field machine (machine No II.).

Table No. 2.

Angle of Closing Switch	Calculated Values of I maximum using Constant X	using Variable X	Experimental Value of I max.
0°	283 amp.	416 amp.	378 amp.
90°	150	240	196
306°	265	350	322

No reliable comparisons can be made from this data, since the following oscillogram shows that the current wave is distorted indicating the presence of harmonics of a higher degree.



The experimental results, however, seem to agree more closely with those values calculated using the actual reactance, which supports the conclusions so clearly indicated in the tests on the rotating armature machine.

Short-Circuit Torque Tests. The results derived from the short-circuit torque tests were not very satisfactory. Obviously, it was impossible to determine experimentally any instantaneous values of torque, but by the deceleration tests employed, a fairly accurate value of the average torque dissipated after short-circuit was obtained. The values of torque calculated from the torque equation (page 17) using both a constant and a variable reactance were not of much use as regards instantaneous values, as no instantaneous experimental values were available with which they could be compared.

The following table, however, gives a comparison of average calculated values with experimental results:

Machine No. I. Rotating Armature				Machine No II. Rotating field.		
θ_1 = angle of Short-Circuit	0°	100°	270°	180°	270°	(1)
$n = \frac{R.P.M.}{60 \times t}$	37.6	26.6	32.2	42.8	46.0	(2)
J	20.5	20.5	20.5	17.4	17.4	(3)
KW = 1.662NJn	37.4	26.5	32.2	24.8	26.6	(4)
Average K.W. Calculated from power formula	46	46	46	37	37	(5)
Torque, lb.ft.	1460	1036	1265	1450	1560	(6)

Comparing values (4) and (5), which give the experimental and calculated values of power respectively, no close agreement is found. It can be said however, that whatever high torque is developed at short-circuit lasts for only a fraction of a second, and is not strong enough in its effects to more than overcome the inertia of the armature so as to affect the shaft. It seems immaterial, then, whether a constant value of reactance or the actual value of reactance is used in the theoretical formula, and this agrees with the conclusions of others that the short-circuit torque is independent of the angle of closing on the e.m.f. wave.

V.

CONCLUSION.

The object of this thesis was to investigate the influence of armature reactance upon the short-circuit current and short-circuit torque of an alternator, to determine the relative accuracy of theoretical formula when either constant or actual values of reactance were used. The conclusions derived directly from the tests and calculations which were made have been stated previously,- in brief, that the calculated values of short-circuit current correspond closely to experimental results when the actual reactance is used; but regarding the short-circuit torque, the instantaneous short-circuit power is dissipated so rapidly that its effects are not serious, and a satisfactory value of average power is obtained from the calculations whether the mean or actual reactance is used.

A large field of investigation is still open to any one who is interested in the phenomena attending the short-circuiting of alternators, and it is hoped that the results of this thesis may help, in some degree, any one who is interested in continuing research that will prove or disprove existing theories.